Ventilation-Perfusion Relationships

**VENTILATION-PERFUSION RATIO**
Ideally, each alveolus in the lungs would receive the same amount of ventilation and pulmonary capillary blood flow (perfusion). In reality, ventilation and perfusion differ depending on the region of the lung.

- On average, the alveolar ventilation is about 4 L/min.
- Normal pulmonary capillary blood flow is about 5 L/min.
- Thus, the ventilation-perfusion (\(\dot{V}/\dot{Q}\)) ratio is 4:5, or 0.8.

Although the overall \(\dot{V}/\dot{Q}\) ratio is about 0.8, the ratio varies markedly throughout the lung:

- In the upright lung, the ventilation-perfusion ratio progressively decreases from the apex to the base.
  - The alveoli in the upper lung portions receive moderate ventilation and little blood flow.
    - The resulting ventilation-perfusion ratio is higher than 0.8 (ventilation > perfusion).
  - In lower regions of the lung, the alveolar ventilation is moderately increased and the blood flow is greatly increased (since blood flow is gravity dependent).
    - Thus, the ventilation-perfusion ratio is lower than 0.8 (perfusion > ventilation).
- Two key relationships to remember are:
  - When the ventilation-perfusion ratio increases, ventilation > perfusion.
  - When the ventilation-perfusion ratio decreases, perfusion > ventilation.

**How the Ventilation-Perfusion Ratio Affects the Alveolar Gases**

- The ventilation-perfusion ratio profoundly affects the oxygen pressure (PAO\(_2\)) and carbon dioxide pressure (PACO\(_2\)) in the alveoli.
  - The normal average PAO\(_2\) of 100 mm Hg is determined by:
    - The amount of oxygen entering the alveoli
    - The removal of oxygen by the capillary blood flow
  - The normal average PACO\(_2\) of 40 mm Hg is determined by:
    - The amount of carbon dioxide that diffuses into the alveoli from the capillary blood.
    - The removal of carbon dioxide from the alveoli by means of ventilation.
- Changing ventilation-perfusion ratios alters the PAO\(_2\) and PACO\(_2\) in the following ways:
  - Increased Ventilation-Perfusion Ratio
The PAO\textsubscript{2} increases because the oxygen does not diffuse into the blood as fast as it enters the alveoli.
- The PACO\textsubscript{2} falls, allowing the PAO\textsubscript{2} to move closer to the partial pressure of the atmospheric oxygen (approx. 159 mm Hg).
- The PACO\textsubscript{2} decreases because the CO\textsubscript{2} is washed out of the alveoli faster than it is replaced by venous blood.
- This ventilation-perfusion relationship is present in the upper segments of the upright lung.
- Refer to Figure 8-3 in the text for an illustration of an increased ventilation-perfusion ratio.

### Decreased Ventilation-Perfusion Ratio
- The PAO\textsubscript{2} decreases because the O\textsubscript{2} moves out of the alveoli and into the pulmonary capillary blood faster than it is replenished by ventilation.
- The PACO\textsubscript{2} increases because the CO\textsubscript{2} moves out of the capillary blood and into the alveoli faster than it is washed out of the alveoli by breathing.
- This ventilation-perfusion relationship is present in the lower segments of the upright lung.
- Refer to Figure 8-4 in the text for an illustration of a decreased ventilation-perfusion ratio.

### Oxygen-Carbon Dioxide Diagram
- The O\textsubscript{2}-CO\textsubscript{2} nomogram summarizes the effects of changing ventilation-perfusion ratios on the PAO\textsubscript{2} and PACO\textsubscript{2} levels.
  - In upper lung regions, the ventilation-perfusion ratio is high.
    - PAO\textsubscript{2} is increasing, and PACO\textsubscript{2} is decreasing.
  - In lower lung regions, the ventilation-perfusion ratio is low.
    - PAO\textsubscript{2} is decreasing, and PACO\textsubscript{2} is increasing.
- Figure 8-5 in the text shows the O\textsubscript{2}-CO\textsubscript{2} diagram.

### How the Ventilation-Perfusion Ratio Affects the End-Capillary Gases
- In end-capillary blood, the oxygen pressure (PcO\textsubscript{2}) and the carbon dioxide pressure (PcCO\textsubscript{2}) mirror changes in the PAO\textsubscript{2} and PACO\textsubscript{2}.
- As the ventilation-perfusion ratio decreases from the top to the bottom of the upright lung:
  - The PAO\textsubscript{2} increases and the PACO\textsubscript{2} decreases.
  - The PcO\textsubscript{2} increases and the PcCO\textsubscript{2} decreases.
- Distal to the pulmonary capillary bed, in the pulmonary veins, the different PcO\textsubscript{2} and PcCO\textsubscript{2} levels are mixed, producing an oxygen pressure of about 100 mm Hg and a carbon dioxide pressure of about 40 mm Hg.
- This PcO\textsubscript{2}-PcCO\textsubscript{2} mixture that occurs in the pulmonary veins is reflected downstream in the PaO\textsubscript{2} and PaCO\textsubscript{2} of an arterial blood gas sample.
As PaCO\textsubscript{2} decreases from the bottom of the lung to the top, the reduced CO\textsubscript{2} levels in the end-capillary blood result in a relative respiratory alkalosis in these regions. Once mixing occurs, the overall pH in the pulmonary veins, and subsequently in the arterial blood, is about 7.35 to 7.45.

Figure 8-7 in the text summarizes the important effects of changing ventilation-perfusion ratios.

**Respiratory Quotient**

- Internal respiration is the gas exchange between the systemic capillaries and the tissue cells.
- The ratio between the volume of oxygen consumed and the volume of carbon dioxide produced is called the respiratory quotient (RQ).
- Normally, the tissues consume about 250 mL of oxygen each minute and produce about 200 mL of carbon dioxide.
- Calculation
  - \( RQ = \frac{\text{CO}_2}{\text{O}_2} \)
  - \( RQ = 200 \text{ mLCO}_2/\text{min.} / 250 \text{ mL O}_2/\text{min.} \)
  - \( RQ = 200 / 250 = 0.8 \)
- Normal value is 0.8

**Respiratory Exchange Ratio**

- External respiration is the gas exchange between the pulmonary capillaries and the alveoli.
  - The gas exchange is between the body and the external environment.
- The quantity of oxygen and carbon dioxide exchanged during 1 minute is called the respiratory exchange ratio (RR).
- Calculation is the same as for the RQ:
  - \( RR = \frac{\text{CO}_2}{\text{O}_2} \)
  - \( RQ = 200 \text{ mLCO}_2/\text{min.} / 250 \text{ mL O}_2/\text{min.} \)
  - \( RQ = 200 / 250 = 0.8 \)
- Normal value is 0.8
- Under normal conditions, the RR equals the RQ.

**How Respiratory Disorders Affect the Ventilation-Perfusion Ratio**

Pulmonary disorders that decrease pulmonary perfusion include:

- Pulmonary Vessel Blockage
  - Pulmonary emboli
A pulmonary ventilation/perfusion scan is a pair of nuclear medicine tests that use inhaled and injected radioactive material (radioisotopes) to measure ventilation and perfusion in all areas of the lungs. An abnormal nuclear lung scan shows areas without nuclear particles (arrows). This finding indicates that pulmonary emboli (blood clots) may be present. A normal lung scan is shown on the right for comparison.

- Obstruction or narrowing of the pulmonary vasculature
  - Atherosclerosis
  - Collagen vascular disease
- Compression of the pulmonary vessels, narrowing their diameter and reducing the capacity for blood flow
  - Pneumothorax
  - Hydrothorax
  - Tumor
- Destruction of the pulmonary vessels through which the blood flows
  - Emphysema
- Decreased cardiac output
- In these respiratory disorders, the affected lung area receives little or no blood flow in relation to ventilation. As a result:
  - The ventilation-perfusion ratio increases.
  - The larger part of alveolar ventilation is dead space ventilation (ventilation without perfusion), which is also called wasted ventilation.
  - The PAO$_2$ increases and the PACO$_2$ decreases.

Pulmonary disorders that decrease pulmonary ventilation include:

- Obstructive Lung Disorders
  - Emphysema
  - Bronchitis
  - Asthma
- Restrictive Lung Disorders
  - Pneumonia
  - Silicosis
  - Pulmonary Fibrosis
• Hypoventilation from any cause
• In these respiratory disorders, the affected lung area receives little or no ventilation in relation to blood flow. As a result:
  o The ventilation-perfusion ratio decreases.
  o A larger portion of the pulmonary blood flow is shunted (perfusion without ventilation), which is not effective in terms of gas exchange.
  o The PAO$_2$ decreases and the PACO$_2$ increases.